# Biological Relevance Affects Object Recognition in Jumping Spiders

Yinnon Dolev

Ximena J. Nelson

*School of Biological Sciences, University of Canterbury, Private Bag 4800, Christchurch, New Zealand.*

Correspondence: Ximena Nelson, ximena.nelson@canterbury.ac.nz

Phone: +64-3-3642987 Ext. 4050

Fax: +64-3-3642590

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**Abstract**

We investigated whether biological relevance affects the perceptual processes underlying prey classification in jumping spiders (Salticidae). We used choice experiments with abstract and realistic representations of prey to test whether *Hypoblemum albovittatum*, a generalist predator, differs in how it classifies prey compared with *Evarcha culicivora*, which specialises on preying on blood-fed *Anopheles* mosquitoes. Unlike *E. culicivora*, *H. albovittatum* preferentially chose realistic over abstract representations of prey. Both species had similar decision times when choosing realistic images, which for *H. albovittatum* was similar to its decision time with abstract stimuli. In contrast, *E. culicivora* was significantly faster at making a decision when these were abstract images of *Anopheles.* These results suggest that *E. culicivora* uses key feature extraction methods when confronted with its preferred prey, but otherwise relies on holistic processing of an object, which appears to be the mechanism used by *H. albovittatum.*

## Introduction

For any predator, a necessary prerequisite to prey selection is object recognition and categorisation, yet, how animals achieve this fundamental task is surprisingly understudied. Visual object recognition is the ability to perceive the physical properties of an object (such as shape, colour and texture) followed by applying semantic attributes to the object (Enns 2004), such as the classification of the object as prey, predator or irrelevant. The diverse natural histories of visual predators have led to vastly different processes of classification of prey items. Some predators make rapid decisions and do minimal classifying of prey into particular types; instead relying on basic key features of an object as identifiers of prey. The use of key attributes is often used by amphibians (Barlow 1953; Lettvin et al. 1959; Heinze et al. 1998), mantises (Prete et al. 2011) and even birds (Bond 2007) to classify an object as prey. These elements include a specific size range, movement in a specific orientation, colour or pattern. In contrast, while little work has been done on visual discrimination abilities in predator-prey interactions, it is well known that many animals, including many invertebrates, are capable of learning complex visual discrimination tasks (Srinivasan 1994; Gierszewski et al. 2013; Fuss et al. 2014). As exemplified by the formation of search images, this ability can be used when hunting (Bond 2007). However, whether closely related animals categorise the same stimulus differently, or even possibly attribute different valence to it, has not been directly explored. Nonetheless, this might be expected when considering predators with different predatory behaviours and preferences.

Predators are commonly divided as generalists, which consume a wide range of different types of prey, or specialists, which tend to consume specific types of prey more often than might be expected given their prevalence in the habitat. Predatory specialists therefore target specific types of prey, and express a preference for those particular prey when given a

choice. Perhaps one of the most interesting questions relating to prey preference is its evolution (Tauber et al. 1993; Pekár 2004; Pekár & Toft 2014) and the parallel evolution of the processes underlying object recognition and categorisation. This is because, crucially, the behavioural traits of prey preference and dietary specialisation rely on a predator's ability to distinguish between different types of prey. Consequently, a comparative approach between specialists and generalists within the same animal grouping is a powerful way to investigate both the perceptual processes underlying object classification, and the salience of different objects to specific animals.

Spiders are generally envisaged as generalists (Bristowe 1941; Wise 1993; Foelix 1996; Wise 2006), yet it is within this group, particularly among jumping spiders (Salticidae), that we find some of the most extreme cases of prey specialisation known. These include spider-eating species (Jackson & Hallas 1986; Jackson 1992; Harland & Jackson 2000, 2006), ant-eating species (Edwards et al. 1974; Cutler 1980; Jackson & Li 2001; Jackson & Nelson 2012) and even a species (*Evarcha culicivora* Wesolowska & Jackson, 2003) that has a particular preference for blood-fed female mosquitoes in the genus *Anopheles* (Wesolowska & Jackson 2003; Jackson et al. 2005; Nelson & Jackson 2006). This East African spider is capable of using vision alone to discriminate between its preferred prey and similar looking male *Anopheles*, female *Anopheles* that have not fed on blood, non-anopheline mosquitoes, as well as various similar-sized non-mosquito prey (Jackson et al. 2005; Nelson & Jackson 2006, 2012). In contrast, most salticids are generalists, showing no preference for specific prey when given the choice between different prey. One such salticid is the New Zealand house hopper, *Hypoblemum albovittatum* (Keyserling, 1882). While little information is available on the natural diet of *H. albovittatum*, personal observations, as well as many years of experience in

75 the laboratory (Tarsitano & Jackson 1992), leads us to conclude that this is a generalist
76 species.

77 Salticids are especially suited for investigation into visual processing and object
78 categorisation because they are highly visual animals that respond readily to digital images
79 on screens. Moreover, salticids are capable of discriminating minute details in a visual scene
80 (Nelson 2010; Nelson & Jackson 2012). This is enabled by a pair of large forward-facing eyes
81 (the anterior median or principal eyes), which are specialised for high resolution vision (spatial
82 acuity), but within a very narrow (c. 2–5°) field of view (Land 1969a; Williams & McIntyre
83 1980; Land 1985; Blest et al. 1990). However, this narrow field of view is compensated for
84 with complex retinal movements that scan up to c. 28° on either side of the body axis (Land
85 1969b). A tiered retina sits at the end of an elongated eye tube attached to the corneal lens,
86 which is part of the exoskeleton. The eye tube is surrounded by six muscles, which enable
87 horizontal, vertical and rotational movement even though the corneal lens is static (Land
88 1969b). In addition, salticids have three pairs of smaller, immobile lateral eyes with a
89 combined visual field of ~360°. These 'secondary eyes' function primarily as motion detectors
90 (Land 1971, 1972; Zurek et al. 2010; Zurek & Nelson 2012).

91 We have previously shown that the mosquito-eating salticid *E. culicivora* not only
92 categorises abstract stick figure representations of a mosquito as prey, but also recognises
93 stick figure *Anopheles* mosquitoes as its preferred prey, even when the comprising elements
94 of the *Anopheles* stick figure are disarranged and disconnected from each other (Dolev &
95 Nelson 2014). Our work on *E. culicivora* demonstrated that this species primarily uses feature
96 extraction methods for recognising at least this kind of prey, without the need of holistic
97 processing.

Here we test whether biological relevance affects the recognition and classification of abstract images of prey in two related predators. Specifically, we predicted that the predatory specialist salticid *E. culicivora* would differ in its ability to classify prey compared with *H. albovittatum*, a generalist salticid hunter, in accordance with the biological significance of the prey to the spider. We tested the prey choice behaviour of *H. albovittatum* in a multi-choice experiment using common prey items from the natural environment of this species; predicting that there would be no preference for any food item. We then used a two-choice test using abstract and realistic images to examine the responses of *H. albovittatum* to abstract images of *E. culicivora*'s preferred prey item – *Anopheles* mosquitoes. For this experiment we predicted that, unlike *E. culicivora*, *H. albovittatum* would preferentially choose realistic stimuli over abstract representations of prey. To test the effects of biological relevance we compared these results with our previous results with *E. culicivora* (Dolev & Nelson 2014).

**Materials and Methods**

(a) General

All testing was carried out between 0800 and 1400 h in a temperature-controlled laboratory set to 24°C, with a photoperiod of 12L:12D (lights on at 07:00). Spiders were housed individually in 1 litre plastic cages with a damp cotton wick for humidity. Spiders were fed to satiation once a week on *Drosophila* spp., but before testing spiders were subjected to a 5–10 day fast. Test spiders were adult (body length, 4.5–5.5 mm) and juvenile (1.5–2.5 mm) *Hypoblemum albovittatum*. This is a locally common and readily identifiable species. Females' have a distinct abdominal pattern and a dark spot on the anterior dorsal part of their cephalothoraces, while males have dark legs and an orange band around their eyes (clypeus).

All spiders were collected from houses and gardens around the University of Canterbury, and were kept in the lab for a minimum of two weeks before use. Gravid females were not tested.

All stimulus images used for tests (Fig. 1) were created using Adobe Photoshop CS5. Figs. 1a and 1c–f (from Crowe 2002) were rendered in black and white and were placed on a transparent background. Image b was a circle approximately the size of a housefly, and image g was a photograph of an *Anopheles gambiae Giles, 1902* mosquito in its typical resting posture, also rendered in black and white with the background removed. Fig. 1h was a stick figure representation of an *A. gambiae* in its typical resting posture (ensuring that the angles between all body parts were maintained) and Fig. 1i was a scrambled disconnected version of Fig. 1h, created so as to not alter the respective angles of any of the elements of Fig. 1h, while ensuring the elements were disconnected and, to humans, no longer resembling a mosquito.

(b) Multi-choice experiment

These tests took place in an arena where six stimuli (Fig. 1a–f) were visible to the test spider. The arena was made from 5 mm PVC sheets and was created by placing six inclined (22°) ramps around a central hexagon (the 'starting platform') placed atop a PVC base (dimensions in Fig. 2). Attached at the top end of each ramp was an electric stimulus mount built using a deconstructed analogue voltmeter, which was placed in front of a white background. The needles of the voltmeters were used to mount the different stimuli by gluing a thin tube to the back of each picture and then sliding the tubes over the needles. All voltmeters were connected to a control unit to trigger stimulus movement. Each trigger consisted of recurrent electric pulses, whose frequency, amplitude and duration could be controlled, causing the voltmeter needles to simultaneously 'jiggle' 15° to each side of the vertical for 2 s (at 5 Hz).

145 These settings were designed to be most noticeable by the spiders, as determined by
146 preliminary experiments.

147 The stimuli were printed life-size on standard photopaper and cut to size. Before each
148 test, we randomised the location of each stimulus within the arena and then the spider was
149 placed in the starting platform at the centre of the arena (under a Petri dish) and was left to
150 calm down for about 4 min. During this time, and throughout the test, the images were jiggled
151 once every 30 s. Tests began when the spider was released.

152 We recorded every time the spiders noticed and stalked a stimulus. Noticing
153 behaviour is characterised by the spider performing an optomotor response to face the
154 stimulus with its anterior median eyes and subsequently staring continuously at the stimulus
155 for several seconds. Stalking behaviour is characterised by the salticid slowly stepping toward
156 the prey with its body lowered while visually fixated on the prey. Both are reliably identifiable
157 behaviours commonly used in spider behaviour experiments (e.g., Nelson & Jackson 2012; Dolev
158 & Nelson 2014). For this experiment we regarded stalking of a stimulus as the spider making a
159 choice. Sessions ended when the spider started stalking a stimulus, walked off the arena, or
160 when 15 min had elapsed without the spider making a choice (the latter two were considered
161 'failed tests' and were used for analyses concerning attrition rate, see below).

162

163 (c) Two-choice test

164 For detailed methods see Dolev & Nelson (2014). Stimuli consisted of videos containing two
165 stimuli (Fig. 1f–i), which moved identically and simultaneously. Some of these stimuli were
166 realistic depictions of potential prey (Fig. 1f, 1 g), while others were stick figure
167 representations of prey (Fig. 1h 1i), to which *E. culicivora* responds in the same manner as
168 realistic images (Dolev & Nelson 2014). Videos were back-projected onto a frosted glass

169 screen through a lens placed 10 mm from the projector. Stimulus motion (two bouts of
170 movement every 10 s) was at a speed of 16°/s and moved up and down at 8° visual angle from
171 the starting position at which *H. albovittatum* were placed. These parameters were selected
172 to maximise the attention of the spiders (Zurek et al. 2010).
173 Experiments were held within an apparatus containing a stainless steel ramp (15 mm
174 wide X 150 mm long; angled up by 25°) in front of the screen. At a distance of 22 mm from
175 the end of the ramp, a stainless steel 'starting box' (11 mm wide X 19 mm high X 22 mm deep;
176 i.e., furthest point 44 mm from top end of ramp) was welded to the ramp complex. The box
177 had a transparent Perspex 'door' wired to an external controller for remote opening. Before
178 each session, which image was on the right and which was on the left was randomised. The
179 spider was placed into the starting box and the door was closed for about 4 min as a calming
180 period, after which, once the spider was away from the door of the starting box, the door was
181 opened and tests began. Tests ended with the spider either pouncing on one of the two
182 images on the screen or jumping/walking off the ramp. Failing these two conditions, tests
183 were stopped after 15 min. Due to the short distance between the screen and the starting
184 position on the apparatus, the spiders were able to pounce without stalking, so only pouncing
185 behaviour was recorded.
186
187 (d) Statistics
188 All analyses were done using SPSS Statistics v.20, GraphPad Prism v.6, and R v.3.0.1. For the
189 multi-choice experiments, $\chi^2$ tests were performed on the spiders' choices of stimuli as well
190 as power analyses using a medium (w = 0.3, see Cohen 2013) effect size. To determine any
191 compass orientation bias, the orientation of the ramp chosen in multi-choice tests was also
192 analysed ($\chi^2$ tests). Spiders were divided into three groupings - female, male and juvenile

193 (juvenile sex cannot be discerned). We used Kruskal-Wallis tests to investigate the effects of
194 the sex or age on both prey choice and decision time (defined as the time elapsed between
195 first noticing a stimulus and initiating stalking behaviour) in both the two-choice and the
196 multi-choice experiments.

197 We used binomial tests to analyse prey choice in the two-choice experiments, and
198 Bonferroni-adjusted $\chi^2$ tests and Fisher exact tests to analyse attrition rates. To analyse the
199 decision time within and between each two-choice experiment, we used t-tests and, where
200 appropriate, Mann-Whitney tests. These tests were also used to analyse data from our
201 previous work on *E. culicivora* (Dolev & Nelson 2014), enabling us to directly compare the
202 decision times and attrition rates for a specialist and for a generalist predator when viewing
203 the same stimuli.

204

205 **Results**

206 In multi-choice tests, 41 (19 females, 15 males and 7 juveniles) out of 123 sessions (33%)
207 ended with the spiders stalking (choosing) an image. The spiders showed no significant
208 preference for any of the six images ($\chi^2$ = 1.585, df = 5, NS, w = 0.3, power = 0.98, Table 1) or
209 the directionality of any of the ramps (ramp 1-6 respectively: $n$= 4, 8, 11, 9, 4, 5; $\chi^2$ = 6.268, df
210 = 5, NS). The sex or age of the spiders also had no significant effect on prey choice ($H$ = 1.355,
211 df = 2, NS, Table 1). Finally, there were no significant differences in the decision time between
212 the different choices ($H$ = 4.456, df = 5, NS; Table 1).

213 In the two-choice experiments, *H. albovittatum* showed a significant preference for
214 the detailed 'realistic' images over the abstract images (Table 2, experiments B and D).
215 However, they showed no preference between the two realistic images used (house fly and
216 mosquito) or the two abstract ones (stick figure mosquito and its disarranged version). There

were significant differences in the attrition rates between the different choice tests (2 X 5 test, $\chi^2$ = 19.7, df = 4, $P$ < 0.001, Table 2), with the attrition rate in experiment A - which consisted of two abstract images - being significantly higher than in any other experiment (Fisher exact test with Bonferroni adjustments, experiments A vs. B: $P$ = 0.003; A vs. C: $P$ = 0.002; A *vs*. D: $P$ = 0.0007; A vs. E: $P$ = 0.0015). There were no significant differences between any of the other pairwise comparisons. No differences were found when comparing the decision time between the experiments ($H$ = 5.998, df = 4, NS, Table 2). Within each two-choice experiment, there were no significant differences in the decision time between the choices (experiments A-E (all NS), respectively: $t$ = 1.046, df = 19; $t$ = -1.223, df = 25, $P$ = 0.233; $t$ = -1.037, df = 28; $t$ = 0.001, df = 27; $t$ = 0.257, df = 21; Table 2).

Using unpublished data (Table 3) from our previous two-choice experiments on *E. culicivora* (Dolev & Nelson 2014) we found significant differences in the decision times between the choices within experiment G ($U$ = 15.0, df = 2, $P$ = 0.001) with the decision time for the abstract image representing a mosquito being shorter than for the realistic image of a fly (Figs. 1f, 1i). This was also the case for experiment H, although the sample size was too small for statistical analysis due to the extreme preference for one stimulus over the other (Table 3). There was no significant difference in the decision time between the two abstract images ($t$ = 0.307, df = 22, NS; experiment F, Table 3).

Comparing decision times in the two-choice experiment of *H. albovittatum* and of *E. culicivora*, we found significant differences in the decision times when faced with abstract images (Fig. 1h, 1i), with *E. culicivora*'s decision time being significantly shorter than that of *H. albovittatum* (Table 2, experiment C and Table 3 experiment G: $U$ = 10.0, df = 2, $P$ = 0.001; Table 2 experiment D and Table 3 experiment H: $U$ = 36.5, df = 2, $P$ < 0.05). We found no difference ($t$ = 0.098, df = 29, NS) in decision times to choose a realistic image of a fly (Table

2, experiment C, and Table 3, experiment G). When comparing experiments A and F (Tables 2 and 3), which have only abstract images (Figs. 1h, 1i), the average decision time of *E. culicivora*, regardless of choice, was significantly shorter than that of *H. albovittatum* ($U$ = 134.0, df = 2, $P < 0.01$).

Comparing the attrition rates in the two-choice experiment of *H. albovittatum* and of *E. culicivora*, we found significant differences in the experiments that showed only abstract images (Fisher exact test, Table 2, experiment A, vs. Table 3, experiment F: $P < 0.001$), with the attrition rate of *E. culicivora* being significantly lower than that of *H. albovittatum.* We found no differences in the attrition rates between the salticid species in experiments that contained the realistic image of a fly (Fisher exact test, Table 2, experiment C, vs. Table 3, experiment G: $P = 0.675$; Table 2, experiment D, vs. Table 3, experiment H: $P = 0.811$).

**Discussion**

These data show how the biological relevance of a stimulus is manifested in the processes of object recognition, with the specialist predator, *E. culicivora*, quickly recognising abstract images as its preferred prey through feature extraction of key elements, while the generalist predator, *H. albovittatum*, appears to use no such short-cut for classification. 'Implicit representation' is the use of key elements alone for creating a broad 'perceptual envelope' of images categorised as prey (Ewert 2004; Prete et al. 2011; Nelson & Jackson 2012). This process would be primarily beneficial for generalist predators making a broad category classification (i.e., 'prey'). We previously showed that *E. culicivora* recognises the abstract images of *Anopheles* mosquitoes specifically as their preferred prey (Dolev & Nelson 2014). This highly specific type of classification could not be the result of a broad-based implicit

representation, but rather, it seems that *E. culicivora* uses a narrow perceptual envelope to classify the stimulus, or 'implicitly identifies' the images specifically as *Anopheles*.

The results of the multi-choice experiment suggest that *H. albovittatum* is a generalist predator. With our relatively low sample sizes we can only rule out a strong preference to a particular prey item. However, for the purposes of this study we can reasonably consider *H. albocittatum* a generalist, as it initiated stalking behaviour roughly equally to each of the six stimuli used, suggesting that it categorised all images as potential prey items. Although a few individuals chose the circle (roughly half the number that chose the other stimuli), it is not entirely surprising that the spiders categorise the circle as a prey item. Many generalist predators, including some salticids, categorise stimuli as prey using only basic key features (Drees 1952; Barlow 1953; Lettvin et al. 1959; Heinze et al. 1998; Prete et al. 2011; Bartos 2013). What is somewhat surprising was the high attrition rate in this experiment, as salticids typically readily respond to stimuli in the lab (Harland et al. 1999). The most likely explanation is that, rather than stalk distant prey, *H. albovittatum* tends to pounce on nearby prey. This suggestion is strengthened by the lower attrition rates in the two-choice experiments, where stimuli were presented at a distance from which spiders could directly pounce on the target. Indeed, in the two-choice tests where a realistic image was presented to *H. albovittatum*, the attrition rates were no different than those of *E. culicivora* from our previous work (Dolev & Nelson 2014). Interestingly, when the spiders were presented only with abstract images, *H. albovittatum*'s attrition rate increased significantly, while *E. culicivora*'s remained unchanged.

Similarly, the decision time prior to an attack on the realistic and abstract images differed between the specialist and the generalist. Given the nature of the two-choice experiment, decision time can be considered as a proxy for how long it takes the spiders to

visually analyse an image. Unsurprisingly, both species took the same amount of time to analyse the image of the fly. However, *E. culicivora* analysed the abstract images (including the scrambled version) significantly faster than *H. albovittatum,* and also significantly faster than they themselves analysed alternative stimuli.

Bednarski et al. (2012) show that the salticid *Phidippus audax* (Hentz, 1845) uses stimulus movement as the key element for categorisation as prey, thus adopting a very large perceptual envelope of this category (including a moving rectangle). In a similar set of studies, Bartos (2007, 2013) showed that the salticid *Yllenus arenarius* Menge 1868 uses four key elements (stimulus length, movement type, congruent location of body parts and number of appendages) for the classification of a stimulus as prey. Furthermore, stimulus length and type of movement are used for classification into two prey categories with distinct escape risks requiring different attack strategies. These key elements create somewhat smaller perceptual envelopes than that of *P. audax*. Together with our data, these exemplify the differences in object categorisation and image analysis that seem to be the result of the evolution of predatory specialisation. One can imagine an evolutionary spectrum, starting with a generalist predator such as *P. audax*, which represents prey as anything that moves 'the right way'. As specialisation evolved, the use of more cues enables the creation of narrower perceptual envelopes and the application of specific prey-catching behaviours, accordingly. At the other end of the spectrum, we find a highly specialised predator, such as *E. culicivora*, with a strong preference for one specific prey which it 'implicitly identifies' and which triggers prey-specific predatory behaviour.

*Hypoblemum albovittatum* and *E. culicivora* appear to classify the same images as different things. *Hypoblemum albovittatum*, being a generalist predator, did not appear to categorise the abstract images as prey items, while *E. culicivora* not only categorised them as

prey, but identified them as preferred prey. *Evarcha culicivora*'s ability to recognise the abstract scrambled mosquito relies on feature abstraction (Dolev & Nelson 2014) and here we show that this recognition and categorisation process is performed more rapidly for abstract stimuli than for realistic stimuli. *Evarcha culicivora* also processed abstract images more rapidly than the generalist salticid. This suggests that the feature extraction processing is a benefit that coevolved with predatory specialisation in *E. culicivora.* The processing of the realistic images used in these tests took longer. It is therefore reasonable to assume that, compared with the quick low-level feature-extraction characteristic of preferred prey recognition, analysing images that lack these features might require higher-level holistic processing.

Our work suggests that, compared with generalists, specialists may use streamlined categorisation processes that facilitate the rapid identification of stimuli relevant to their specific life histories. Indeed, one can envision that it is the very strength of the implicit representation strategy (basing prey-recognition or representation on 'algorithms', rather than underlying neural components) that has paved the way for the evolution of predatory specialisation, either by narrowing the subset of objects that elicit appetitive behaviours, or by having some of these objects elicit a stronger appetitive behaviour.

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**Figures and Tables**

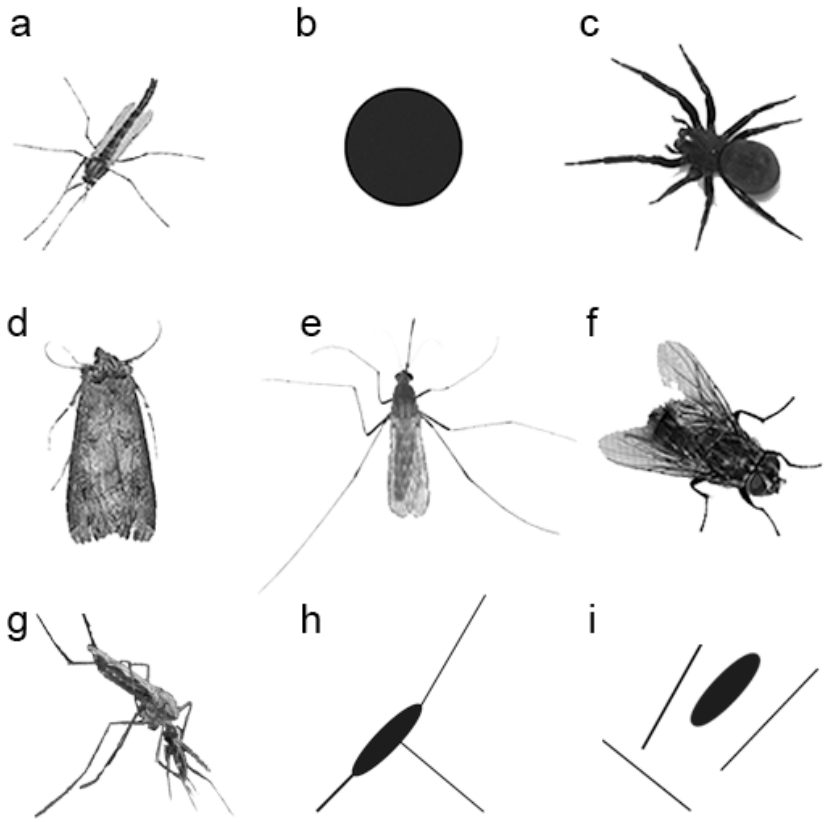


**Figure 1** Stimuli used in the multiple prey-choice experiment with *Hypoblemum albovittatum*. a. *Chironomus zealandicus* (midge). b. Circle. c. *Badumna longinqua* (spider). d. *Eudonia angustea* (moth). e. *Culex pervigilans* (mosquito). f. *Musca domestica* (fly). g. *Anopheles gambiae* (mosquito). h. *Anopheles gambiae* stick figure. i. Disarranged *Anopheles gambiae* stick figure.

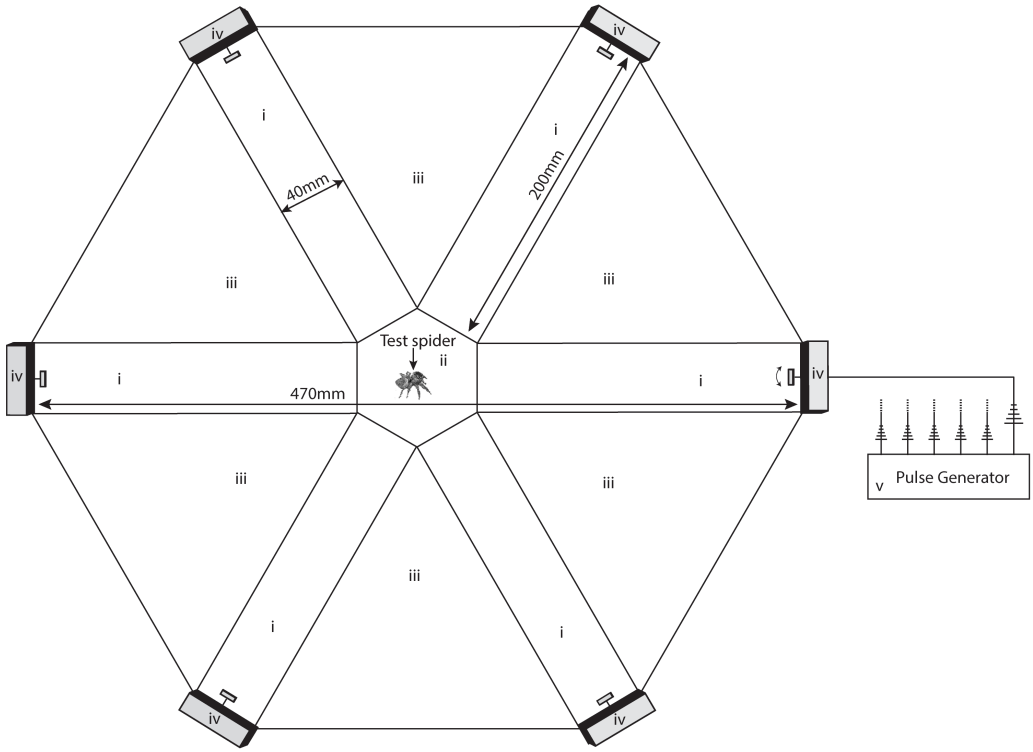


**Figure 2** Test apparatus used for multi-choice experiment for *Hypoblemum albovittatum*. Roman numerals are as follows: i. Angled PVC ramps (x 6). ii. Starting platform. iii. Areas between ramps. iv. Holders on which stimuli were placed at the end of each ramp. v. Pulse generator connected to each stimulus holder.

474 **Table 1** Results from multi-choice prey tests for *Hypoblemum albovittatum.* F =

475 female; M = male; J = juvenile; dt = decision time (s).

| | Circle | Fly | Midge | Mosquito | Moth | Spider |
|---|---|---|---|---|---|---|
| Selected n (%) | 4 (9.8) | 8 (19.5) | 7 (17.1) | 7 (17.1) | 8 (19.5) | 7 (17.1) |
| Mean dt ± SEM | 250 ± 114 | 489 ± 126 | 213 ± 39 | 244 ± 71 | 228 ± 101 | 188 ± 42 |
| *n* for F; M; J | 3; 0; 1 | 4; 4; 0 | 2; 1; 3 | 3; 2; 2 | 4; 3; 1 | 3; 4; 0 |

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**Table 2** Stimuli used and attack rate of *Hypoblemum albovittatum* in two-choice tests. dt = decision time (s). P values are of binomial tests. n = total spiders used, including those that made no choice.

| Experiment | Image 1 | Pounced on image 1 (mean dt ± SEM) | Image 2 | Pounced on image 2 (mean dt ± SEM) | *P* | *n* (mean dt ± SEM) | Attrition (%) |
|---|---|---|---|---|---|---|---|
| A |  | 12 (387 ± 40) |  | 9 (323 ± 47) | 0.66 | 63 (360 ± 31) | 67 |
| B |  | 7 (398 ± 131 |  | 20 (558 ± 63) | <0.05 | 42 (516 ± 58) | 36 |
| C |  | 7 (466 ± 96) |  | 23 (381 ± 35) | <0.05 | 47 (401 ± 35) | 36 |
| D |  | 8 (332 ± 51) |  | 21 (332 ± 80) | <0.05 | 43 (332 ± 42) | 33 |
| E |  | 13 (473 ± 85) |  | 10 (440 ± 96) | 0.68 | 34 (458 ± 62) | 32 |

**Table 3** Stimuli used and attack rate of *Evarcha culicivora* in two-choice tests. dt = decision time (s). P values are of binomial tests. n = total spiders used, including those that made no choice.

| Experiment | Image 1 | Pounced on image 1 (mean dt ± SEM) | Image 2 | Pounced on image 2 (mean dt ± SEM) | *P* | Total *n* (mean dt ± SEM) | Attrition (%) |
|---|---|---|---|---|---|---|---|
| F |  | 13(187 ± 57) |  | 11 (215 ± 74) | 0.84 | 32 (200 ± 45) | 31 |
| G |  | 20 (108 ± 34) |  | 8 (375 ± 26) | <0.05 | 48 (185 ± 34) | 42 |
| H |  | 20 (145 ± 26) |  | 2 (496 ± 22) | <0.05 | 35 (177 ± 30) | 37 |